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MODELLING DD-963 CLASS MATERIAL READINESS

by

Jonathan E. Will

September 1988

Thesis Advisor: Dan C. Boger

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Modelling DD-963 Class Material Readiness

by

Jonathan E. Will
Lieutenant Commander, United States Navy
B.S., U. S. Naval Academy, 1978

Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

This thesis develops several simple statistical models of DD-963 Class material readiness using data from 1981 to 1986. The models are exercised to demonstrate their ability to explain and predict surface warship material readiness. Ability to forecast future readiness is found to be low. Two different measures of readiness are compared and found to be redundant. Accurately measured data on personnel manning, resources spent on ship repair and resources spent on ship modernization could be useful in improving the ship material readiness models developed here.

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I. INTRODUCTION

A. BACKGROUND

The Navy maintains a large force of ships, submarines and aircraft to perform its assignments. At any one time, however, not all of these are able to operate as designed; some have material casualties (i.e., broken equipment) that reduce their effectiveness, and others are in planned maintenance periods for upgrading and repair. The units which can operate as designed are termed "ready."

Overall readiness can be defined as the ability of a Navy unit to perform all its designed missions. Material readiness--the ability of all the unit's equipment to function as designed--is a component of overall readiness.

Since a small combat force with high material readiness is the short-term equivalent of a much larger force with low readiness, it is desirable to maintain high levels of material readiness. Doing this requires money--to buy spare parts, to pay for the maintenance facilities that the Navy operates, etc. Therefore, the Navy's budget limits the readiness that can be achieved. Within existing budget constraints, the Navy wants to maximize the readiness of its forces.

For several years, the Program Resource Appraisal Division of the Office of the Chief of Naval Operations (OP-81) has used a mathematical model to predict the material readiness of Navy aircraft. As inputs, the model takes planned funding in various categories of aircraft maintenance and repair. The output of the model is the predicted proportion of the Navy's aircraft which will be able to perform all designed missions--the "Fully Mission Capable" (FMC) rate. The FMC concept is widely used and accepted in the Naval aviation community. The model has been helpful in determining budget needs and in allocating funds to meet FMC goals. It gives insight into which areas of the budget result in the biggest improvements in aircraft FMC rate per dollar spent.

A similar model designed for use with surface ships is needed. The same model cannot be used because a ship is a fundamentally different combat system from an aircraft. The Surface Warfare community has no concept analogous to the aviation FMC rate, so a measure of surface ship material readiness (hereafter referred to simply as readiness) is needed. OP-81 has created such a measure by using the Navy's existing Casualty Report (CASREP) system.

A CASREP is a message sent from a ship's Commanding Officer to his operational and administrative chain of command when the ship experiences a material casualty that the crew cannot fix within 48 hours. CASREPs are grouped into one of three categories depending on the impact of the casualty. The C3 and C4 categories indicate a major material casualty--an equipment failure that prevents the ship from performing one or more of its primary missions (e.g., anti-submarine warfare, anti-air warfare, anti-surface warfare, mobility, etc.). CASREPs are considered a reliable indicator of the ship's material condition because of the visibility and importance of these official messages. By definition, a ship without C3 or C4 CASREPs has no equipment problems that prevent it from performing all of its primary missions.

Over the past four years, OP-81 has engaged several defense contractors to develop mathematical models of the relationship between resources (budget dollars) and ship readiness using the time free of C3 and C4 CASREPs as the measure of ship readiness [Refs. 1,2]. These models have varied in complexity and utility. Even after this work, however, several questions of interest remain:

- Is there a "better" measure of surface ship material readiness?
- What variables can best explain and predict future surface ship material readiness?
- What data should be collected to support the use of such a model?

B. PURPOSE

The objective of this thesis is to develop two mathematical models of surface ship material readiness. The first model will use the OP-81 measure of ship material readiness, the time free of C3 C4 CASREPs. The second model will use a related but different measure of readiness, C3 and C4 CASREP-days. This measure simply sums over a fiscal year the product of C3 and C4 CASREPS and the number of days on which each casualty existed. For example, two C3 or C4 CASREPs lasting the entire year of 365 days would result in 730 C3, C4 CASREP-days for that year.

The models will then be compared to see which one is better able to predict and explain ship readiness. The process of developing these two models will help to answer the questions listed above and give insight into the general problem of predicting ship material readiness.

II. DATA

Data are needed on time free of C3/C4 CASREPs, on C3/C4 CASREP-days and on potential explanatory factors. Two data sets of interest are found. The first is obtained from the Naval Sea Systems Command (NAVSEA). Entitled "Visibility and Management of Operating and Support Costs, Ships" (VAMOSC), it was used by at least one of the OP-81 contractors in building a complex ship readiness model [Ref. 2: pp.2/17-2/20]. The second data set is from the Center for Naval Analyses (CNA), entitled "Factors Affecting Ship Material Condition." It is being used for ongoing studies of ship equipment condition at CNA [Refs. 3, 4 , 5].

The VAMOSC data are unclassified, but parts of the CNA database are classified at the Secret level. In order to keep this thesis at an unclassified/Official Use Only level, only unclassified data from the CNA database are used.

Both of these data sets are very large, containing information on the entire fleet of surface ships and submarines. To limit the breadth of the study, only one class of surface ships is analyzed. The DD-963 (SPRUANCE) class of destroyers is chosen for several reasons. The 31 ships in this class constitute a good sample size, and all but one of them were in commission by 1980. The last ship was not commissioned until 1983 and is therefore omitted from the study because of the resulting missing data.

A change in the reporting requirements for CASREPS took place in 1980. Therefore, data from fiscal years 1981 to as recently as possible (1986) are used. Having 30 ships for each of the six years results in 180 data points for the study.

Each variable available for the study is listed in the Appendix. A general discussion of the database and its structure follows.

A. VAMOSC DATA

The Visibility and Management of Operating and Support Costs, Ships (VAMOSC) data set is maintained by NAVSEA to study and manage the costs of operating and maintaining the ships in the Navy. It contains information on a fiscal-year basis on each ship in the Navy. This information is held in both then-year dollars and constant dollars. The form of constant Fiscal Year 1986 (FY-86) dollars is chosen for this study in order to eliminate the effects of inflation.

About 100 separate variables are available for each hull. These data are in three general categories:

- direct unit costs
- intermediate maintenance costs
- depot-level maintenance costs

Direct unit costs are the costs of operating the ship (paying the crew, buying fuel, etc.) and the costs of organization-level maintenance (repairs performed by the ship's crew) and are broken down into three classifications--personnel, material and purchased services. Material includes fuel, lubricants, repair parts and supplies. About 30 variables are available on each ship in this category.

Intermediate maintenance costs are costs involved in ship repair performed by the Navy's intermediate-level maintenance facilities, which include all tenders and repair ships as well as the Shore Intermediate Maintenance Activities. Money spent on each ship is broken down according to whether the maintenance activity is afloat or ashore, and is further divided into the areas of labor and material. Six variables are available in this category.

Depot-level maintenance is repair work performed by organizations with facilities and skills equivalent to the original shipbuilder. These organizations include shipyards (both publicly and privately owned) and the overseas Ship Repair Facilities operated by the Navy in the Pacific Ocean. This category has the majority of the information held by the VAMOSC database--about 65 variables are available for each ship. This information is broken down into four groups: scheduled repairs (regular overhauls and selected restricted availabilities), unscheduled repairs (restricted and technical availabilities), fleet modernization program, and other (including Naval Aviation Depot work).

Each of these groups is broken down into money spent in public shipyards, private shipyards or ship repair facilities. For the publicly owned facilities, the money spent is further broken down into labor, material and overhead. This information is not available for private shipyards for proprietary reasons.

B. CNA DATA

Some of the data from CNA is similar in nature to the VAMOSC data, but the structure of the CNA database is different--the basic unit of CNA data is a month instead of a fiscal year. The CNA data are generally of a more detailed nature than the VAMOSC data, which are very general.

In order to use these two data sets together, it is necessary to process the CNA data to give it a fiscal year structure.

The data on C3 and C4 CASREPs is from this file. About 55 different possible explanatory variables are also included. These fall into four general categories:

- ship activities
- spare parts requested
- enlisted manning and turnover
- Commanding Officer information

Ship activities include about 20 separate variables with widely varied information. This category includes the proportion of time each ship spent underway, steaming, in maintenance, etc. It also includes the results of material inspections conducted by the Board of Inspection and Survey and each ship's fleet (Atlantic or Pacific).

The category of spare parts requested contains five variables with information on how many spare parts of various types and classifications were requested by or found on the ship. These data are generated by the requisitions submitted by the ship.

Enlisted manning and turnover includes 26 variables concerning the crew of the ship. Six are on the turnover of the crew, broken down by shipboard department--Combat Systems, Engineering, and overall. The remaining variables are levels of enlisted personnel aboard, broken down both by shipboard department and by paygrade groups (junior enlisted (E1-E3), petty officers (E4-E6), and Chief Petty Officers (E7-E9)). These variables are available both in relation to wartime mobilization requirements and as raw counts of personnel aboard.

Information about the Commanding Officer of each ship includes his relative seniority and his previous experience as a department head and executive officer aboard ship.

C. COMMENTS ABOUT THE DATA

An examination of the data shows that many of the potential explanatory variables in both databases are probably unrelated to the material readiness of the ships (i.e., manning level in administrative divisions). Additionally, many variables are closely related to other explanatory variables in one or both of the databases. For these reasons, although a large volume of data is available for the study, only a portion of the data can be considered useful.

The VAMOSC database has been approved by the Chief of Naval Operations for fiscal decision-making purposes. This fact gives some confidence that the data it contains are reliable. The CNA data have not been approved for decision-making purposes but are also expected to be of relatively high quality because of their previous use and refinement at CNA.

III. MODELS

A. PRIMARY MODEL

The primary model uses the OP-81 measure of ship readiness, the time free of C3 and C4 CASREPS. Based on this measure, a ship with no C3 or C4 CASREPS during a year would have 365 days free of major casualties. The theoretical range of this measure is 365 (best) to 0 (worst).

Regression analysis is the natural choice of the analytical tools available to create such a model because the explanatory variables are continuous. In order to keep the model as simple as possible, single equation multiple linear regression is chosen. Based on the author's experience in maintenance aboard ship, all potential explanatory variables are screened for possible inclusion in a model. A simple, standard linear model is outlined:

Readiness = constant plus linear function of the following general variables:

- number of repair parts ordered aboard the ship
- manning levels of senior enlisted personnel
- turnover rates of enlisted personnel
- results of material inspections by Board of Inspection and Survey
- time and/or money spent in maintenance availabilities
- ship activities
- which fleet the ship was in (Pacific or Atlantic)

In mathematical notation, the primary model can be represented by

$$y_1 = c_1 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_6 + a_7x_7 + u_1$$

where

y_1 = readiness, in terms of days free of C3 and C4 CASREPs

c_1 = constant

x_1 = number of parts ordered

x_2 = enlisted manning levels

x_3 = enlisted personnel turnover rate

x_4 = material inspection results

x_5 = resources expended in maintenance

x_6 = ship activities

x_7 = fleet of ship

u_1 = disturbance term: effects of random fluctuations and excluded explanatory variables

and where the a_i represent the coefficients of the corresponding x_i in this linear model.

A constant is necessary in this model to account for a baseline level of days free of C3 and C4 CASREPs, with the explanatory variables present to adjust this baseline.

1. Relationships of Explanatory Variables to Readiness

The general categories of explanatory variables are chosen because each is related in some way to material readiness. For example, number of repair parts ordered is clearly linked with corrective maintenance--more repair parts ordered implies that more equipment is breaking.

High manning levels of senior enlisted personnel (E4-E6 and E7-E9) --the experienced repairmen aboard ships--provide required numbers and quality of people for timely correction of material problems. Higher turnover rates of these personnel result in more time required to fix casualties because some casualties recur, and the "corporate memory" of men who have been part of the crew for a year or more is extremely helpful.

In-depth material inspections provide a good measure of the quality of the preventive maintenance program aboard a ship, and reflect the current material conditions aboard the ship.

Ship activities can have a considerable effect on the ship's material condition. The age of the ship, the length of time since its last overhaul and its operational status (forward-deployed ships get priority treatment when they experience material casualties) are examples of these factors.

Atlantic and Pacific fleets operate in somewhat different physical and leadership environments, causing a possible geographical bias in CASREPs filed.

The relationships between maintenance and readiness are the most complex. During most maintenance periods, two basic activities are performed--repair of broken equipment and installation of new or upgraded ship systems. These two activities have different effects on the material readiness of the ship. Repairs tend to terminate CASREPs, and alterations tend to generate CASREPs when the new (and usually more complex) ship systems fail at some time in the future. Repair and alteration activities

take place simultaneously, so it may be difficult to discriminate between CASREP generation and CASREP termination effects.

There is also a difference in the extent of modifications done by shipyards and tenders. Major modifications to ship systems are generally performed by shipyards. Because of their inherent complexity, these modifications will often lead to material failures later in the ship's life. Modifications accomplished by tenders tend to be relatively minor in scope. The narrower extent of these modifications results in fewer later failures. Distinguishing between the effects of major and minor modifications should be possible since these are generally performed by different organizations.

Overall, more CASREPs require more maintenance.

2. Redundancy of Some Explanatory Variables

For each of the seven general categories of potential explanatory variables, usually several related variables are actually available. For example, there are five different variables for number of repair parts ordered--depending on whether or not the parts were in the ship's Coordinated Shipboard Allowance List (COSAL), whether they were in stock when requested, etc. About 80 variables are directly related to time and or money spent in various types of maintenance. Only inspection results and fleet of ship do not have multiple related variables.

Within each general category, one or more variables are chosen for inclusion in the model. Each variable is chosen because it has a unique relationship with material readiness. For example, in the family of repair parts ordered, the number of ordered allowance list parts and ordered non-allowance list parts normally stocked aboard the ship is chosen because it is the best measure of significant equipment breakdown. No other variable is picked from this family because these variables are very closely related and contain a high proportion of duplicate information. Each variable chosen from the database in this way for inclusion in the model is marked with an asterisk in the Appendix.

3. Determination of Probable Signs of Coefficients in Model

The coefficients in a linear regression model can be regarded as partial derivatives of the corresponding explanatory variables. That is, the coefficients represent the amount of change in the response variable that would result from a unit change in the corresponding explanatory variable if all other explanatory variables are held constant.

Based on this interpretation of the coefficients and on the relationships between the various explanatory variables and readiness discussed above, the probable signs of

the coefficients (a_i) are determined. For example, number of repair parts ordered, turnover rates, time in maintenance, age of ship and time since overhaul should have a negative sign because all of these factors are related to more C3 and C4 CASREPs and thus fewer days free of major CASREPs. Enlisted manning levels and inspection results should have a positive coefficient because higher levels of these factors are related to more days free of major casualties. The sign of the variable for fleet is uncertain since it is not known which coast might be more likely to file CASREPs.

B. ALTERNATE MODEL

The alternate model also uses C3 and C4 CASREPs as a measure of ship readiness, but in a different way. Readiness is measured in terms of C3 and C4 CASREP-days per year. For example, two C3 or C4 CASREPs lasting the entire year of 365 days would result in 730 C3/C4 CASREP-days this year. The theoretical range of this measure starts at zero (best possible) and is unbounded. It is important to investigate this alternate measure of readiness because it could be more sensitive to multiple casualties than the primary measure and might be easier to predict.

A mathematical representation of the alternate model is

$$y_2 = c_2 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_7 + u_2$$

where

y_2 = readiness, in terms of C3 and C4 CASREP-days

c_2 = constant (different from c_1 in primary model)

x_i = explanatory variables, as in primary model

b_i = coefficients of explanatory variables

u_2 = disturbance term: effects of random fluctuations and excluded explanatory variables

This model uses the same seven basic variables in a simple linear relationship. In this case, however, the signs of the coefficients should be the opposite of the signs in the primary model because the alternate model used an inverted measure of readiness. As in the primary model, a constant is necessary to account for a baseline level of C3/C4 CASREP-days.

IV. ANALYSIS OF PRIMARY MODEL

The first task is to obtain the data sets from CNA and NAVSEA and to place them in a usable form in the Naval Postgraduate School mainframe computer. An appropriate software tool--FORTRAN, APL (A Programming Language) or the GRAFSTAT graphics and statistics analysis package--is used at each stage of the analysis. Due to different formats, times of receipt, and degree of difficulty in getting the data into the mainframe computer, the CNA data are available for use considerably in advance of the NAVSEA data. The CNA data are aggregated into a yearly structure to be compatible with the NAVSEA data.

A. EXPLORATORY DATA ANALYSIS

The CNA data are first checked numerically and graphically to look for unusual or nonsensical values. The bounded nature of many variables involved (for example, days free of CASREPS, percent time in overhaul, enlisted manning levels, etc.) eases this task. There are no cases of obvious incorrect values.

Simple plots are made of the various explanatory variables against the time free of C3 and C4 CASREPS. These plots show that some explanatory variables have clear relations to the dependent variable, but that most variables are not obviously related. Examples of these plots follow.

Figure 1 on page 12 shows an example of an explanatory variable (repair parts ordered) that appears to have a relationship with the response variable, days free of C3 and C4 CASREPS. It can be seen that the relationship is an inverted one--higher values of repair parts ordered are correlated with lower values of days free of CASREPS. This figure confirms the intuitive idea that the coefficient for repair parts ordered in the primary model should be negative.

A plot of the shipwide manning level of Chief Petty Officers (E7-E9) reveals some problems that were not apparent from previous screening of the data. Figure 2 on page 13 shows that some ships had less than 30 percent of required manning of these important personnel during a given year--a highly unlikely event. Similar problems are found in the data values for E4-E6 manning levels. These personnel are less experienced but also are important in operating and maintaining a ship. Since these data are probably erroneous, any models using personnel manning levels would be inaccurate.

Development of the model begins following completion of these exploratory plots.

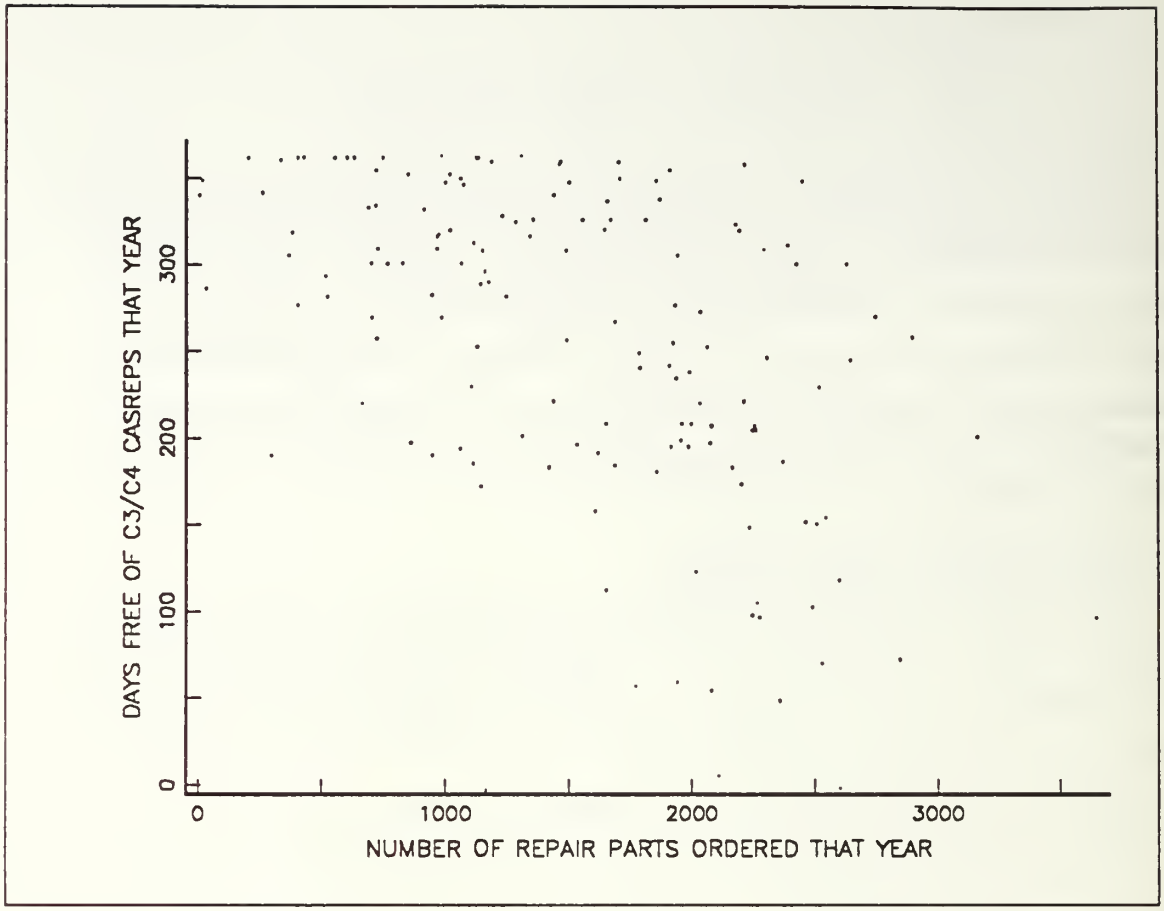

Figure 1. Sample Data Plot: days free of C3/C4 CASREPs as a function of number of repair parts ordered. A regression line can be imagined from the upper left to the lower right of the data.

B. ORDINARY LEAST SQUARES REGRESSION

A brief summary of terms and methods used in ordinary least squares regression is included for clarity.

A statistical routine uses the data to calculate the values of the coefficients (a_i) of the explanatory variables in the model. The calculated coefficients are those that minimize the sum of the squares of the residuals in the model. Residuals are the difference between the fitted values (those obtained by inputting the data for each explanatory variable) and the observed values of the response variable. The calculated coefficients determine the linear model.

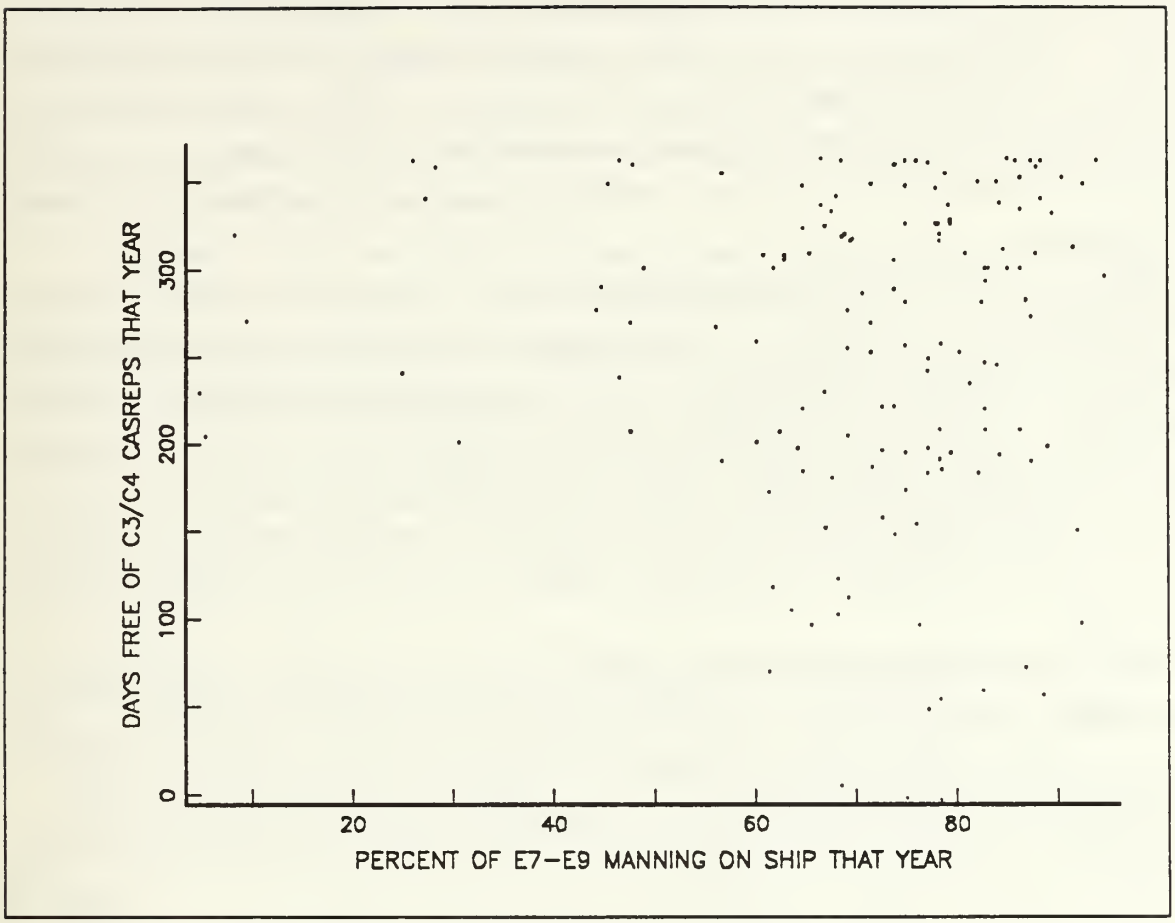

Figure 2. Sample Data Plot: days free of C3/C4 CASREPs as a function of E7-E9 manning. Values on left hand side of plot are highly unlikely.

The statistical routine determines a single number as an estimate for each of these coefficients, but there is an uncertainty in each estimate--coefficients calculated to be nonzero may not be significantly different from zero. A true zero coefficient would imply no real relationship between the explanatory variable and the response variable.

If the disturbance terms (the effects of random fluctuations plus excluded explanatory variables) in the model are distributed normally, a "t-test" can be performed to check whether the calculated coefficients are significantly different from zero. In this test, the test statistic t is

$$t = \frac{a_i}{se_i}$$

where se_i is the standard error (a measure of uncertainty) of the coefficient a_i. If the residuals of the regression are distributed normally, this statistic has the t-distribution, and the result can be checked for statistical significance. Roughly, if the resulting t-statistic is greater than two, the coefficient is statistically significant, meaning that there is less than a five percent chance that a coefficient calculated to be different from zero is actually zero.

T-tests are of two types: one-sided and two-sided. If the sign of the coefficient is not known beforehand, a two-sided test is performed; this test simply checks to see if the coefficient is significantly different from zero. If the sign of the coefficient is known beforehand, a one-sided test is performed. This test determines if the coefficient is both significantly different from zero and is also of the correct sign. The procedures for both tests are almost identical. In the case of the one-sided test, assuming that the calculated sign is correct, a test statistic of two implies a significance level of about 0.025. [Ref. 6: pp.181-198]

Based on the interpretation of the coefficients as partial derivatives of the explanatory variables, the signs of most coefficients in this model are known beforehand and a one-sided t-test is used. In the case of the fleet variable, a two-sided t-test is used because the probable sign of the coefficient for this explanatory variable is not known in advance.

Throughout the analysis, a significance level of 0.025 is taken to be the minimum acceptable for including an explanatory variable in the model.

C. DEVELOPING THE PRIMARY MODEL--ITERATIVE APPROACH

Initial computer runs indicate which chosen explanatory variables are individually significant in a regression model. For example, percent of time in overhaul is significant individually, and percent of time in maintenance is "close" to significance, with a t-statistic of about 1.8. When these variables are placed together as explanatory variables in one model, however, both are insignificant. This is because they contain very similar information--by definition, time in maintenance includes time in overhaul as well as time in less extensive maintenance availabilities. This situation is called multicollinearity. Multicollinear explanatory variables tend to dilute the significance of a model; therefore, only one of this family is retained in the model, the time in overhaul.

Another difficulty with this pair of variables is that the signs of their coefficients are opposite to those expected. The reason for this apparent contradiction is as follows: when ships go into a major maintenance availability, CASREPs on equipment that will

be fixed during the overhaul or maintenance period are usually cancelled at the start of the maintenance period. Thus more time in overhaul or maintenance is related to more days free of C3/C4 CASREPs. The greater strength of the time in overhaul variable is probably due to the fact that overhauls are longer than other maintenance availabilities and result in more CASREP cancellations.

The number of repair parts ordered is found to be a strong explanatory variable individually. When it is placed in a model with percent of time in overhaul, the percent time in overhaul becomes insignificant because of multicollinearity with the number of repair parts ordered. This relation was previously unsuspected, but makes sense: once in overhaul, with few ship systems operating and most maintenance work being performed by shipyard personnel, the crew itself orders few parts. Since number of repair parts is stronger in explaining days free of CASREPs, it is retained in the model; time in overhaul is dropped.

When placed in the same model with number of repair parts ordered, all other individually significant explanatory variables are insignificant at the 0.025 level. Only one variable, fleet of ship, is even close to significance, with a t-statistic of about 1.7.

The manning levels of senior enlisted personnel are not significant variables even when taken individually. This fact is not surprising, based on the apparent problems in the data.

1. Delayed Effects of Explanatory Variables

The reversed sign of the time in overhaul variable demonstrates that the apparent short-term effect of an overhaul is to reduce the number of active CASREPs along with the number of parts requisitions. The next logical step is to look for longer-term effects of overhauls. The possibility of delayed effects of maintenance had not been considered in the original model for the sake of simplicity. However, it now appears that consideration of a time-delayed (lagged) overhaul variable in a new version of the model is necessary to include the CASREP-producing effects of an overhaul. The use of lagged values of explanatory or response variables as additional explanatory variables is an accepted approach in econometrics [Ref. 6: pp. 343-371]. Also, a previous study on readiness used this approach successfully with explanatory variables [Ref. 2 : p. 1/6]. Therefore, the previous year's percent of time in overhaul is entered as an explanatory variable for the current year's time free of C3/C4 CASREPs. Results are significant at the 0.025 level.

The successful use of lagged values of an explanatory variable leads to consideration of lagged values of the response variable itself in the model, since some ship systems tend to be "lemons", with recurring problems in the same equipment. The sign of the coefficient is reasoned to be positive, since casualty-plagued ships tend to remain in that condition. When the previous year's time free of C3/C4 CASREPs is entered as an explanatory variable for the current year's time free of CASREPs, the results are significant.

Due to the change in requirements for filing CASREPs in 1980, it is necessary to drop 30 data points in performing this lagging operation, since 1980 CASREPs are not equivalent to those in later years. This leaves 150 data points for analysis.

2. Consideration of Other Explanatory Variables

At this point, variables not included in the original model are entered into the regression to see if any might be significant. This is done to find explanatory variables that might have been overlooked in the model-building stage. It is not expected that any variables will be significant.

One variable, the manning level of junior enlisted personnel (E1-E3), has a statistically significant coefficient. This result seems strange, since personnel in these paygrades are least experienced and least skilled. When the variable is plotted against the days free of C3 and C4 CASREPs, problems similar to those in senior enlisted manning levels (see Figure 2 on page 13) are found.

Going back to the original CNA monthly-structured database, the monthly E1-E3 manning level is plotted against days free of C3/C4 CASREPs in that month (see Figure 3 on page 17). The data are clearly erroneous--all values are either below 40 percent or above 80 percent, with frequent changes from month to month from below ten percent to above 90 percent (not discernable from Figure 3 on page 17). Since the manning level on a ship never fluctuates in this way, it is clear that there is a major error in this variable, and it was by chance that junior enlisted manning level is statistically significant. This variable is not used in any model.

Based on these observations, it appears that the personnel manning level data in the CNA database are erroneous. Although this study is unable to use these data on personnel manning, accurate personnel data could be significant explanatory variables for ship material readiness.

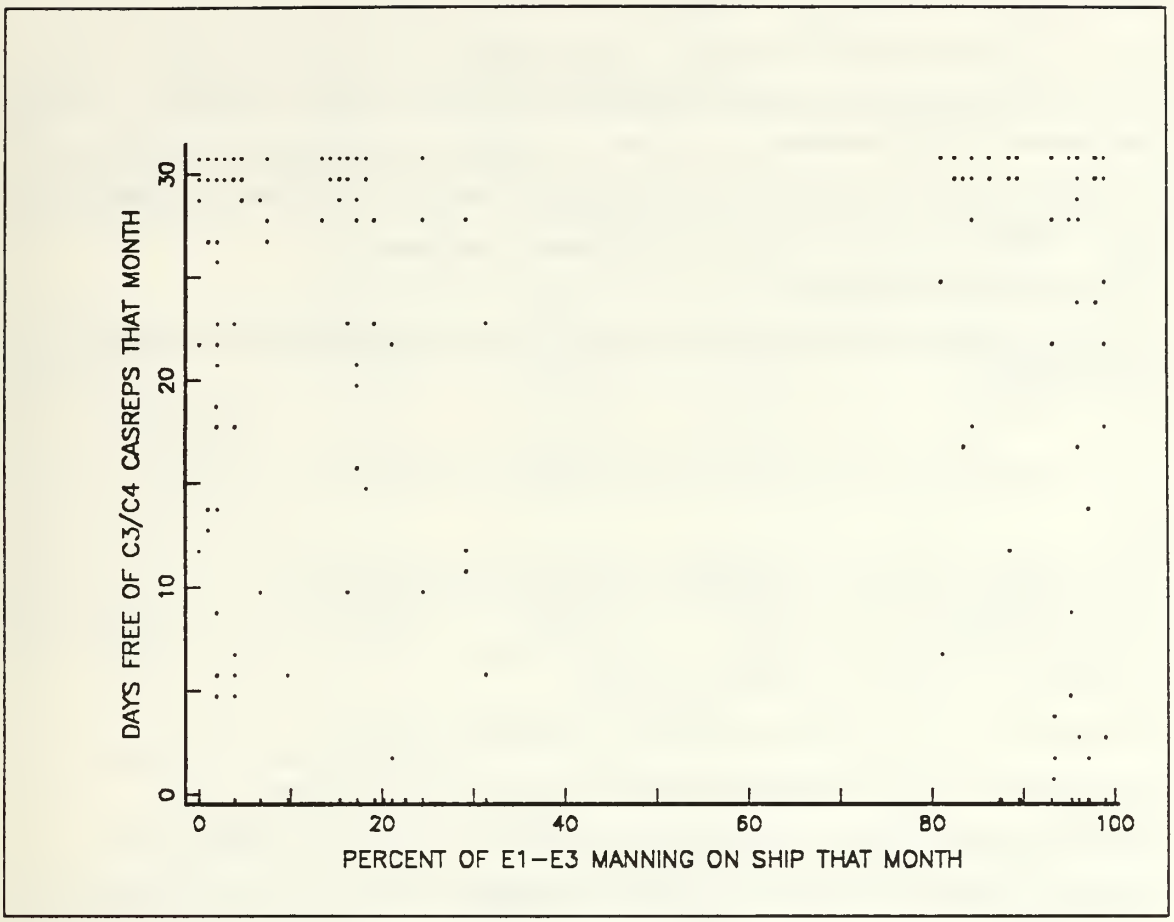

Figure 3. Personnel Data Problems: days free of C3/C4 CASREPs versus E1-E3 manning. Data for three of 30 ships in the study are shown.

3. Consideration of Data Transformations

Transformations of the data are not used because the data are not distributed in a way lending to improvement in results from transformations.

4. VAMOSC Data

Once the VAMOSC data are available, exploratory data analysis similar to that conducted on the CNA data is performed. No problems are found.

Fiscal variables of interest are then put into the regression program, as indicated by asterisks in the Appendix. The VAMOSC data are scaled from dollars into thousands of dollars to keep the coefficients of the model of the same order of magnitude as those obtained using the CNA data. This approach prevents possible numerical problems in

software being used. Only two variables have significant coefficients: Technical Availability[1] (TAV) labor and TAV material. These variables were initially projected to have negative coefficients because more maintenance is related to more CASREPs, as discussed above. TAV labor enters the model with a negative coefficient, but the calculated coefficient for TAV material is positive, indicating that more maintenance is related to fewer CASREPs. This problem requires further investigation.

5. Initial Model Results

The initial results of the primary model using all five significant explanatory variables are

$$y_1 = c_1 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5$$

where

y_1 =days free of C3 and C4 CASREPs, in days (on a yearly basis)

c_1 =constant or intercept in days

x_1 =number of repair parts ordered, in units

x_2 =previous year's days free of C3 and C4 CASREPs, in days

x_3 =percent of time in overhaul during the previous year, in percent

x_4 =money spent for labor in technical availabilities, in thousands of 1986 dollars

x_5 =money spent for material in technical availabilities, in thousands of 1986 dollars

Note that the x_i here are not the same as those proposed in the original primary model. The a_i here are the fitted coefficients of the linear model based on calculations using the data. Their values are listed in Table 1 on page 19 along with the other numerical values of interest for the model at this stage.

R^2 is the proportion of the total variation in the response variable explained by the regression model. The standard error of the regression is a measure of the variability of the results of the model. Smaller standard errors imply more precision in the model.

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1 A Technical Availability is an unscheduled maintenance availability that does not prevent the ship from carrying out its mission.

Table 1. INITIAL PRIMARY MODEL RESULTS

$R^2 = 0.38$				
Standard Error of Regression = 73 days				
Explanatory Variable, x_i	Point Estimate of Coefficient, a_i	Standard Error of Estimate, se_i	T-statistic, $\frac{a_i}{se_i}$	Significance Level
intercept	297	24.3	--	--
repair parts	-0.0515	0.00875	5.9	0.0000001
previous year days free of CASREPS	0.234	0.0696	3.4	0.0006
previous year percent of time in overhaul	-0.962	0.296	3.3	0.0008
TAV labor	-0.649	0.229	2.8	0.0026
TAV material	0.804	0.352	2.3	0.011

6. VAMOSC Data Problems

a. Multicollinearity

An important assumption in the linear model is that the explanatory variables and thus the data values themselves are linearly independent. The above five explanatory variables are in the model because their t-test results indicate significant coefficients. To examine the assumption of independence, the linear correlation coefficients[2] between all pairs of variables in the model are calculated.

2 Linear correlation coefficients range from -1 to 1 in value. A value of 1 indicates an exact linear relationship, as in y = x. A value of 0 indicates no linear relationship, and negative values indicate an inverted relationship, as in y = -x.

Table 2. LINEAR CORRELATION COEFFICIENTS

Variable, x_i	repair parts ordered	previous year days free of CASREPs	previous year percent time in overhaul	TAV labor	TAV material	days free of CASREPs, y_1
repair parts ordered	1					
previous year days free of CASREPs	-0.28	1				
previous year percent time in overhaul	0.07	0.30	1			
TAV labor	0.13	-0.01	0.19	1		
TAV material	0.11	-0.02	0.17	0.92	1	
days free of CASREPs, y_1	-0.51	0.28	-0.21	-0.22	-0.15	1

Table 2 shows the high linear correlation between the TAV labor and TAV material explanatory variables. It is then necessary to determine the effect of keeping these variables in the model, because the multicollinearity could explain the unanticipated sign of the TAV material coefficient.

A small side study is performed in which each of the two TAV variables is used as the response variable in a regression using repair parts ordered, lagged overhaul time and lagged time free of CASREPs as explanatory variables. In each case, the R^2 is insignificant (about 0.04), and the residuals of these two regressions are highly correlated (linear correlation coefficient of 0.92). Therefore, it is believed that the simple correlation coefficient of these two TAV variables (0.92 as listed in Table 2) would not be noticeably altered in the presence of the other explanatory variables; the redundant information contained would not be reduced.

In examining this problem further, each of the two TAV variables is separately entered into the regression package as an explanatory variable along with the previous three explanatory variables (repair parts ordered, lagged overhaul time and

lagged time free of CASREPs) to observe its performance with time free of CASREPs being the response variable. Results are listed in Table 3 on page 21. TAV labor alone again has the expected negative coefficient, but the significance of the result is diluted to less than 0.025. When TAV material is entered into the regression package without labor, its regression coefficient is not significantly different from zero at the 0.025 level.

Table 3. MULTICOLLINEARITY EFFECTS ON REGRESSION RESULTS

TAV Variable	Coefficient	Stand. Error	T-statistic	Significance
labor material (taken together)	-0.649 0.804	0.229 0.352	2.8 2.3	0.0026 0.011
labor, alone	-0.168	0.093	1.8	0.033
material, alone	-0.101	0.14	0.77	0.22
labor plus material	-0.0828	0.058	1.4	0.074

Note that when TAV labor and material are placed together in a model, they have an offsetting effect; their coefficients are of the same magnitude but are opposite in sign.

Inclusion of multicollinear variables in a regression model often increases the standard errors of the affected variables. This results in unstable coefficient estimates and reduces the significance of t-tests conducted, frequently making the explanatory variables insignificant. This had been the case for all previous related variables observed in the study. However, with the TAV labor and TAV material variables, in spite of the relatively large standard errors and unstable coefficients, the results of t-tests are still significant. It should be noted that throughout this exercise of checking for multicollinearity, the estimates of coefficients and standard errors for each of the other three explanatory variables in the model remain almost constant. Based on the above it is decided to drop the VAMOSC variables from the model. Further support for this action is discussed below.

b. Checking for Stability

The effect of running the model with certain data points excluded is examined next. In the case of the TAV labor and TAV material variables, certain data points are relatively far from other data points. These isolated points are known as "high leverage points" [Ref. 7: pp. 249-255] because a single point can have a disproportionate effect on the outcome of the regression model.

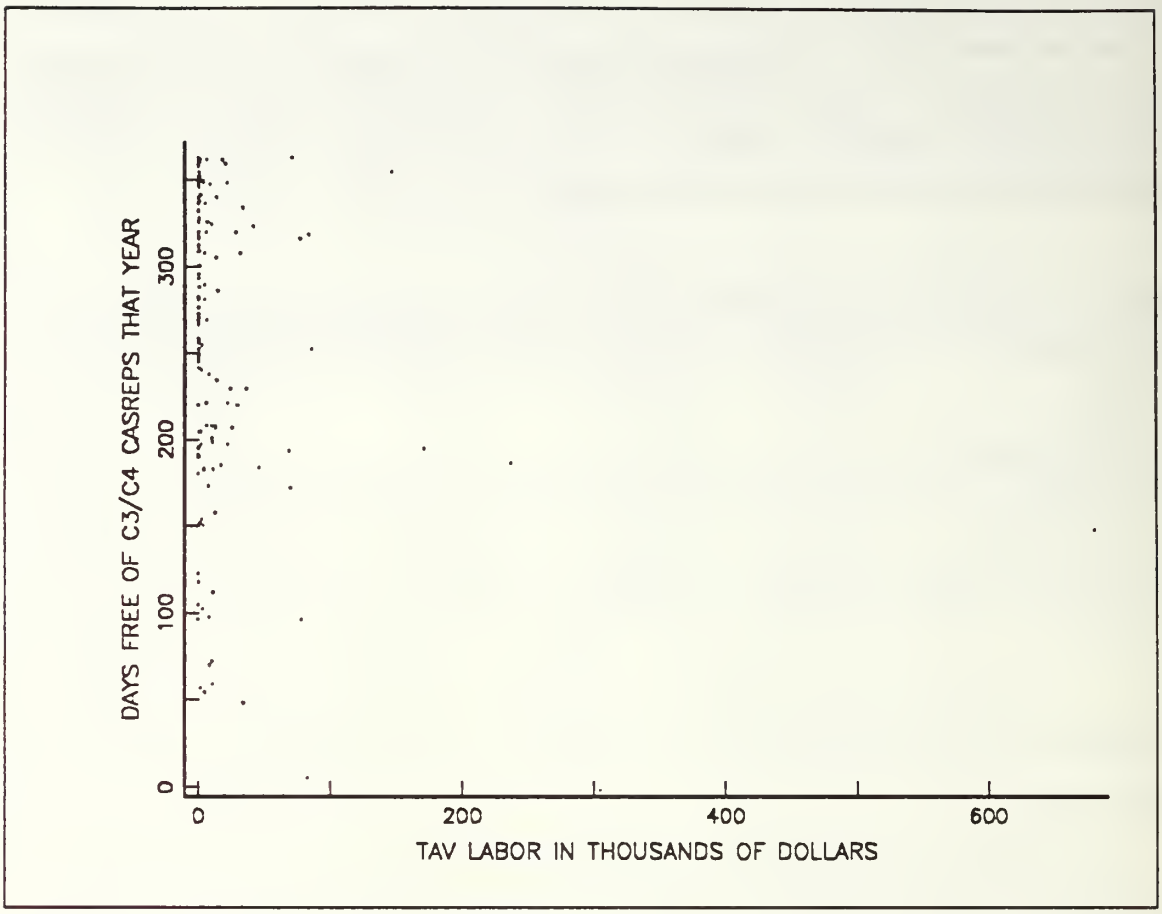

Figure 4. Illustration of High Leverage Points

In Figure 4 on page 22, the placement of a line fitted to the data can vary considerably if any or all of the five rightmost data points are excluded from consideration. Also, the large number of zero values in this data can tend to throw off the regression solution. None of these data values was clearly wrong or miscopied, but there could be strong effects on the resulting model.

Accordingly, regressions are run again, this time dropping one point at a time on the extreme right of Figure 4, with five points finally being dropped. Estimates of coefficients and standard errors vary considerably. T-test results are inconsistent--sometimes the t-test statistic degrades and sometimes it improves. Some of this effect is undoubtedly related to the multicollinearity of the TAV variables.

Combined with the results of the multicollinearity investigation, this exercise results in dropping both the TAV labor and TAV material explanatory variables from the model.

The other three explanatory variables have no isolated points, due in part to the bounded nature of the lagged values of days free of CASREPs and percent of time in overhaul.

D. INTERMEDIATE PRIMARY MODEL

When these two VAMOSC explanatory variables are dropped, the model is

$$y_1 = c_1 + a_1x_1 + a_2x_2 + a_3x_3$$

where

y_1 =days free of C3 and C4 CASREPs (on a yearly basis)

c_1 =constant or intercept, in days

x_1 =number of repair parts ordered, in parts

x_2 =previous year's days free of C3 and C4 CASREPs, in days

x_3 =percent of time in overhaul during the previous year, in percent

Numerical values of interest for this model are listed in Table 4. Note the similarities in this iteration of the primary model to the initial primary model listed in Table 1 on page 19. The exclusion of the TAV variables has little effect on the model, and R^2 is reduced only slightly, from 0.38 to 0.34.

Table 4. INTERMEDIATE PRIMARY MODEL RESULTS

R^2 = 0.34				
Standard Error of Regression = 75 days				
Explanatory Variable, x_i	Point Estimate of Coefficient, a_i	Standard Error of Estimate	T-statistic	Significance
intercept	297	24.9	--	--
repair parts	-0.0535	0.00891	6.0	0.00000008
previous year days free of CASREPs	0.233	0.0710	3.3	0.0007
previous year percent time in overhaul	-1.06	0.297	3.6	0.0003

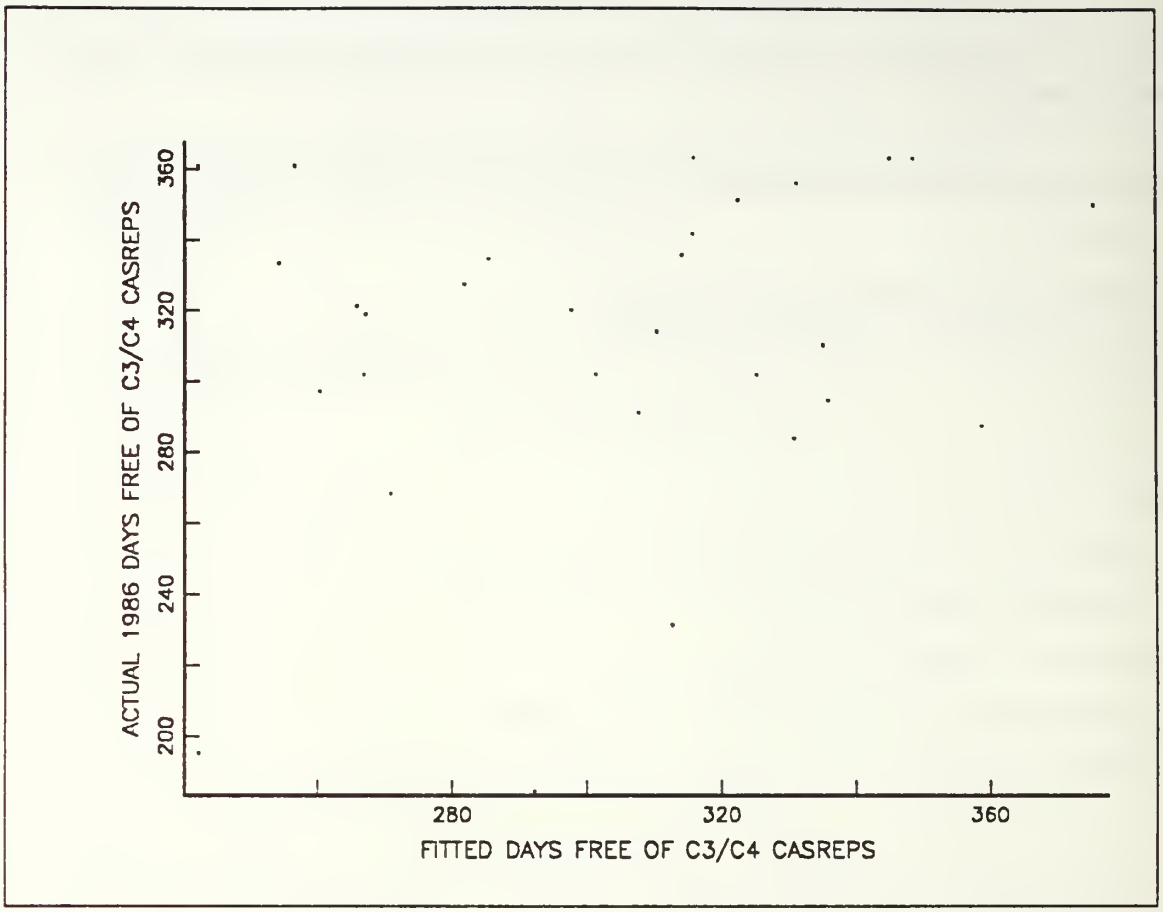

Figure 5. Demonstration of Primary Model: plot of actual days free of C3/C4 CASREPs in 1986 against days free of CASREPs fitted by primary model using 1986 data

This model provides "fitted" values of the days free of C3 and C4 CASREPs based on the values of the explanatory variables, and these values can be compared with the actual observed days free of C3/C4 CASREPs. Figure 5 on page 24 displays the use of 1986 data for the explanatory variables in exercising the model. Fitted values came within one standard error (75 days) of the actual value of the response variable for 25 of the 30 ships. The maximum difference between fitted and actual values was 1.6 standard errors, or 106 days.

Though this model is useful for explaining readiness and removes about one third of the variation in material readiness, it is not able to predict the material readiness of a ship for the upcoming year, because one of the explanatory variables (number of repair

parts ordered) cannot be controlled and is not known until the upcoming year is over. A lagged repair parts ordered variable is not significant in the t-test, so the effect of repair parts cannot be included in a predictive model.

E. FINAL PRIMARY MODEL

By dropping the number of repair parts ordered from the model, the only remaining explanatory variables are the lagged variables, whose values are known in advance. In dropping the repair parts ordered from the model, the current year's percent time in overhaul again becomes significant: current time in overhaul is collinear only with repair parts ordered (linear correlation coefficient is -0.62). Although current year's time in overhaul is not known precisely in advance, its values can be projected fairly accurately, unlike the number of repair parts ordered. The inclusion of this variable helps to diminish the effects of dropping the most significant explanatory variable from the model.

A very simple predictive model is constructed using these three variables, as follows:

$$y_1 = c_1 + a_1x_1 + a_2x_2 + a_3x_3$$

where

y_1 =days free of C3 and C4 CASREPs, in days (on a yearly basis)

c_1 =constant or intercept in days

x_1 =previous year's days free of C3 and C4 CASREPs, in days

x_2 =percent of time in overhaul during the previous year, in percent

x_3 =percent of time in overhaul this year, in percent

Numerical values based on 1981-1985 data for this model are listed in Table 5 on page 26. With the removal of repair parts ordered, the values are considerably different from those in the intermediate primary model as listed in Table 4 on page 23.

Table 5. PRIMARY PREDICTION MODEL RESULTS

R^2 = 0.23				
Standard Error of Regression = 81 days				
Explanatory Variable, x_i	Point Estimate of Coefficient, a_i	Standard Error of Estimate	T-statistic	Significance
intercept	186	18.0	--	--
previous year days free of CASREPS	0.323	0.0744	4.3	0.00003
previous year percent time in overhaul	-1.33	0.317	4.2	0.00004
percent of time in overhaul this year	0.897	0.292	3.1	0.0014

To avoid bias in predicting days free of CASREPs in 1986, this model is calculated using only the 120 data points from 1981 to 1985. The differences between this predictive model and the previous intermediate model are due mainly to the different explanatory variables, not to the fewer data points used.

The price of exchanging the most significant explanatory variable for a less significant one is evident. This model explained less than a fourth of the variation in the days free of C3/C4 CASREPs, and it had a larger standard error. The low R^2 of this model reflects a poor ability to predict future readiness of individual ships.

To demonstrate the use of this model, the 1985 data (with 1986 values for time in overhaul) are used to forecast the days free of C3/C4 CASREPs for each ship in 1986. Results are shown in Figure 6 on page 27.

In 14 of the 30 ships, the prediction model is able to forecast within plus or minus 60 days the number of days free of C3/C4 CASREPs. In 20 of the 30 ships, predictions are within plus or minus 90 days of the actual values. With the larger standard error in this model (81 days), 20 of the 30 predictions are within plus or minus one standard error of the actual value.

It can be seen that the predictions are conservative, although conservatism is not a design characteristic of the model. Actual days free of C3/C4 CASREPs are generally better than those predicted.

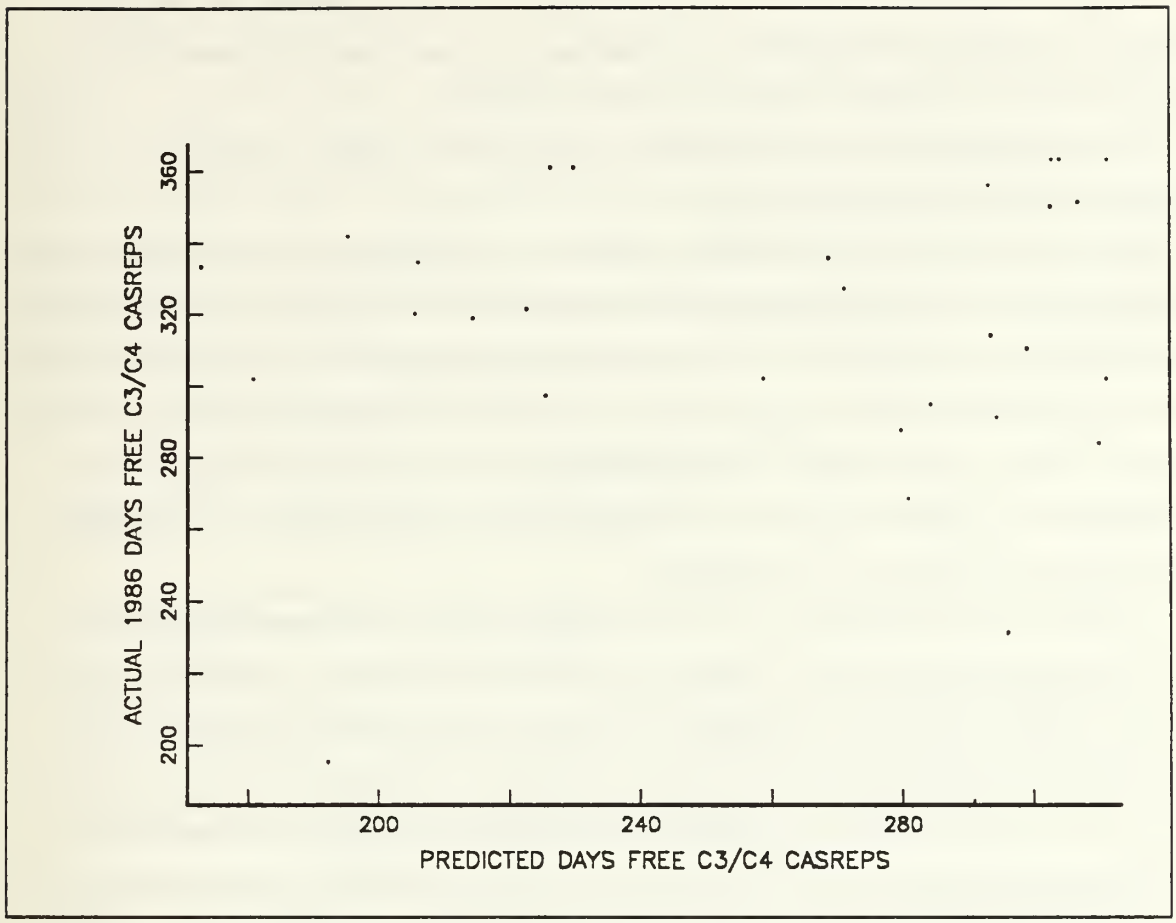

Figure 6. Demonstration of Primary Prediction Model: plot of actual days free of C3/C4 CASREPs in 1986 against days free of CASREPs fitted by primary prediction model using 1985 data, with 1986 values for current year's time in overhaul.

F. EXAMINATION OF ASSUMPTIONS

Several assumptions are necessary in order to perform ordinary least squares regression. It is necessary to check that these assumptions are met in order to use such a model. The assumptions are:

- explanatory variables are fixed
- explanatory variables are linearly independent
- residuals are distributed normally with mean zero
- residuals are homoscedastic (have constant variance with respect to explanatory variables and ships) and are not autocorrelated

The first assumption is based on popular utilization of multiple linear regression methods. The explanatory variables span their ranges well and results of the analysis are conditional, given the value of the explanatory variables.

The assumption of linear independence of explanatory variables is validated by the previous checks for multicollinearity.

To check the assumption of normal disturbances, a Kolmogorov-Smirnov test of the residuals [Ref. 8: pp. 552-559] is performed by the GRAFSTAT package. An adjustment is necessary due to the necessity of estimating the sample variance of the hypothesized normal distribution. Stephens' method [Ref. 9] is used, and a significance level of 0.10 is obtained. Based on this result, it is decided that the assumption of normal distribution of residuals is reasonable. This is a prerequisite for meaningful tests of hypotheses concerning the coefficients of the regression.

To check the last assumption of constant variance with no autocorrelation, the residuals of the regression are plotted against each explanatory variable. Residuals for each of the 30 ships are plotted as a function of time, and Durbin-Watson statistics [Ref. 6: pp. 314-317], which are a measure of autocorrelation, are computed for each ship. Ideally, all of these tests should show that the residuals of the regression have no pattern, indicating good adherence to the last assumption of the model. Plots involving residuals from all 30 ships show no structure, but when each ship is examined individually, problems arise. Autocorrelation of ship residuals (meaning that a ship's residuals are related to its residuals from previous years) and heteroscedasticity (differences in the variability of one ship's residuals as compared to another ship's) are both apparent.

It is necessary to investigate the effect of not meeting the assumption of homscedasticity and no autocorrelation.

1. Checking for Structural Change

The first step in this process is to check the data to ensure they are "uniform" in the sense that there was no change in the underlying process causing CASREPs during the time period of the data. The statistical test for structural change [Ref. 6: pp. 207-211] involves taking time subsets of the database, performing regressions on these subsets, and determining whether the model coefficients from each subset are significantly different. The data are divided into subsets of 1981-1983 and 1984-1986, and the test finds no evidence of structural change over these subsets.

2. Transformed Model

With no structural change in the database, a data transformation specifically designed to correct for autocorrelation and heteroscedasticity is found in the literature [Ref. 10: pp. 616-620]. This transformation uses the information contained in the data to correct these problems. The transformation is nonlinear and has two stages: the first stage removes the time correlation of the residuals of the regression model and the second stage removes the effects of the differing variability among the ships. The transformation exploits all the information available in the data to obtain the most efficient estimators of the primary prediction model.

A brief explanation of the transformation is as follows:

- each ship's residuals from the primary prediction model are used to determine an individual ship autocorrelation parameter
- using this parameter, the response and explanatory data for each ship undergo a first-order autoregressive transformation
- a second ordinary least squares regression is performed on these transformed data. The residuals from this regression are less autocorrelated, and they are used to estimate the individual sample variance in the time free of CASREPs for each ship.
- using the sample variance computed for each ship, the data undergo a second transformation to remove the inherent heteroscedasticity.
- a final ordinary least squares regression is now run on the twice-transformed data

When the transformed model is run, the value of R^2 obtained is 0.72, a large improvement over the 0.23 value of R^2 for the primary prediction model. But because the variables in the transformed model have no physical meaning, a direct comparison of these statistics is not valid. The transformed model can be used to predict future values of readiness only after its results are retransformed back into the original units of days free of C3, C4 CASREPs. When this is done, there is more variation in the transformed model than in the final primary prediction model. See Figure 7 on page 30 for a display of these predictions, and compare to Figure 6 on page 27. Nine of the 30 predicted readiness values are greater than 365 days free of CASREPs when transformed back into original units, with one forecast of 1100 days free of CASREPs.

The assumptions of homoscedasticity and no autocorrelation are satisfied by the transformed model better than by the original primary model, but the transformed model is not practical due to the increased variability of its forecasts. Some of this is probably due to the short time span of the database.

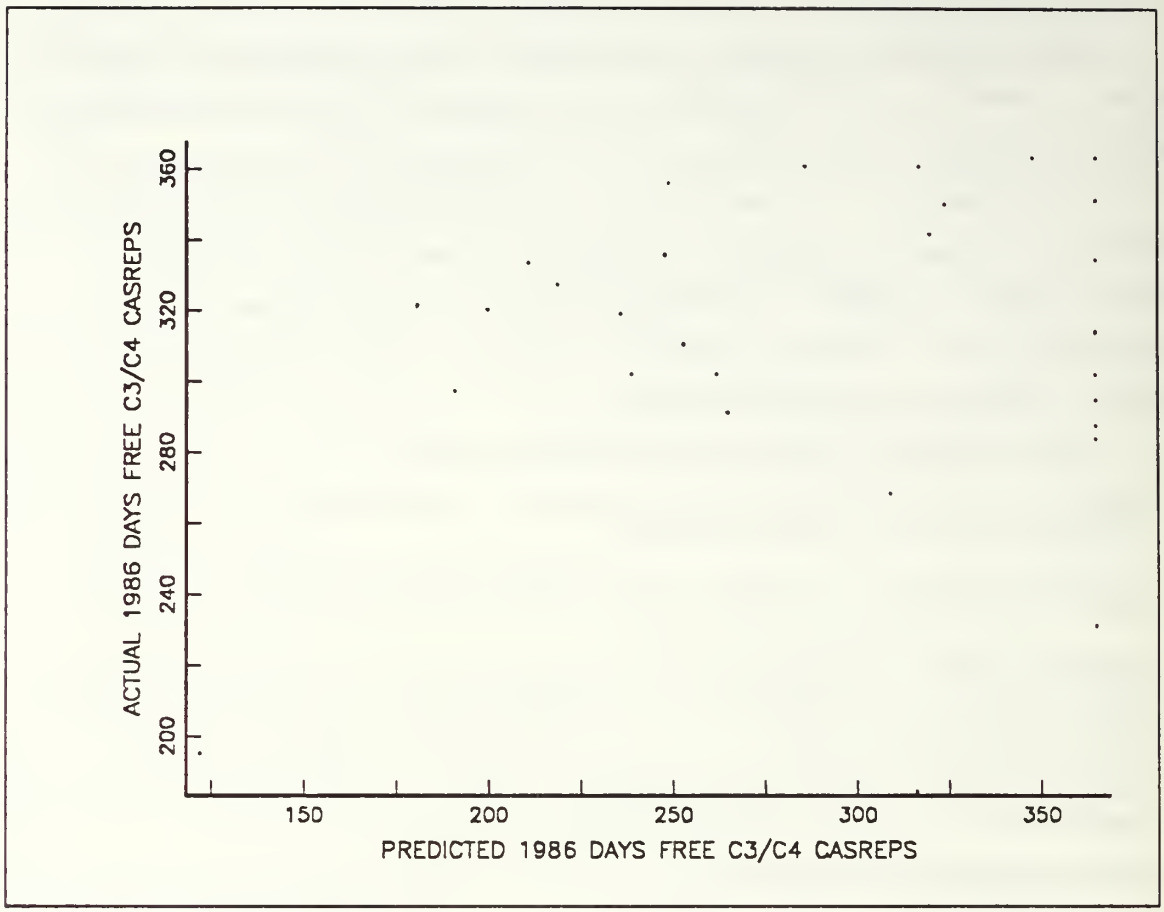

Figure 7. Results of Retransformation: plot of predicted 1986 days free of CASREPs and actual 1986 days free of CASREPs produced by retransforming the values from the transformed model back into units with physical meaning. Predicted values greater than 365 days free of CASREPs are truncated to 365.

This excursion to better satisfy the model assumptions of no autocorrelation and homoscedasticity is not helpful. It appears that the primary prediction model is more useful in predicting material readiness despite its autocorrelated and heteroscedastic characteristics.

V. ANALYSIS OF ALTERNATE MODEL

The analysis of the alternate readiness model is very similar to that of the primary model. Since the same databases are used for the explanatory variables, the only new exploratory data analysis necessary is for the response variable, C3/C4 CASREP-days. No problems are noted, but it is obvious that this measure of readiness is more variable than days free of C3/C4 CASREPs.

Once ordinary least squares models are run, results are remarkably parallel to those of the primary model. The same explanatory variables are consistently found to be significant in both of the models. The effects of the multicollinearity of TAV labor and TAV material variables are virtually identical. Investigation of possible high leverage points has the same results.

The reason for these similarities is found in a simple plot of the primary measure of readiness against the alternate measure, as seen in Figure 8 on page 32. Except for a few data points that represent ships with "bad" years for C3 and C4 CASREPs, the two measures of readiness are closely related. The linear correlation coefficient between the two measures of readiness is -0.82, indicating a strong, inverted linear relation.

This plot suggests further investigation into the relation between the two measures of readiness. It is then noted that the sum of days free of CASREPs and C3/C4 CASREP-days during a year is frequently 365; in other words, there is often either zero or one C3 or C4 CASREP at a time on many ships. Thus the alternate measure of readiness is rendered redundant: the original idea of having a second measure of material readiness that is sensitive to multiple ongoing C3 and C4 CASREPs is defeated.

For consistency, lagged values of the alternate readiness measure are used as explanatory variables in the alternate model, just as lagged values of the primary readiness measure are used in the primary model.

The results of the alternate model using all three significant explanatory variables are

$$y_2 = c_2 + b_1 x_1 + b_2 x'_2 + b_3 x_3$$

where

y_2 =C3 and C4 CASREP-days, in CASREP-days (on a yearly basis)

c_2 =constant or intercept, in CASREP-days

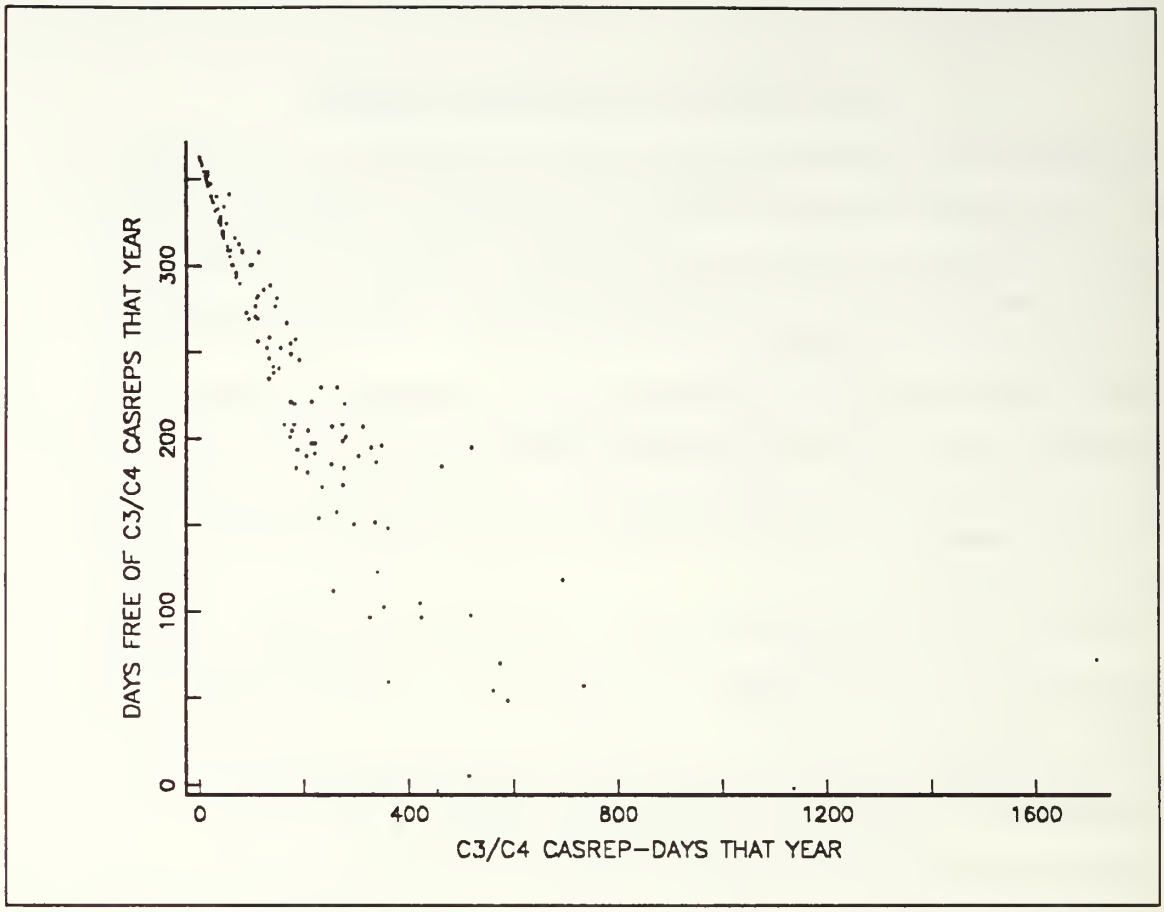

Figure 8. Relation between Primary and Alternate Readiness Measures

x_1 =number of repair parts ordered, in parts

x'_2 =previous year's C3 and C4 CASREP-days, in CASREP-days

x_3 =percent of time in overhaul during the previous year, in percent

b_i =fitted coefficients calculated from the data

Numerical results for this model are in Table 6 on page 33. This model corresponds to the intermediate primary model listed in Table 4 on page 23. Note the large difference in the standard error of the regression.

Table 6. INTERMEDIATE ALTERNATE MODEL RESULTS

R^2 = 0.31				
Standard Error of Regression = 181 days				
Explanatory Variable	Point Estimate	Standard Error of Estimate	T-statistic	Significance
intercept	-68.7	35.7	--	--
repair parts ordered	0.105	0.00214	4.8	0.00005
lagged C3/C4 CASREP-days	0.257	0.0594	4.4	0.00003
lagged percent time in overhaul	2.06	0.700	2.9	0.0023

The numerical measure of the ability of the model to explain C3 and C4 CASREP-days, R^2, is very close to that for the primary intermediate model. The signs of the coefficients are as expected: opposite those of the primary model for parts ordered and percent time in overhaul, and the same for the lagged response variable.

This model is then used to compare the fitted values of C3/C4 CASREP-days for 1986 to the observed values for that year. For the 30 ships in the class, 16 of the fitted values are within plus or minus 60 CASREP-days of the actual values, and 21 fitted values are within plus or minus 90 CASREP-days of the actual values. The precision of the alternate model appears less than that of the primary model because of the unbounded nature of the alternate measure of readiness and the resulting greater variability. With the standard error of the regression of 181 C3/C4 CASREP-days, 28 of the 30 fitted values are within plus or minus one standard error of the actual values.

A. ALTERNATE PREDICTION MODEL

Once again, as in the primary model, the number of repair parts ordered is dropped from the model in order to make a predictive model. Here, the current year's percent time in overhaul is not included in the final alternate prediction model since, strictly speaking, it is not known in advance. The exclusion of this explanatory variable makes little difference in the model or in its ability to predict readiness in the upcoming year.

This model again uses the 1981-1985 data, 120 data points, in order to avoid bias in predicting values for 1986 C3/C4 CASREP-days. The coefficients and statistics of interest for this prediction model are shown in Table 7, and the model is demonstrated in Figure 9 on page 35.

Table 7. ALTERNATE PREDICTION MODEL RESULTS

R^2 = 0.20				
Standard Error of Regression = 208 days				
Explanatory Variable	Point Estimate	Standard Error of Estimate	T-statistic	Significance
intercept	80.0	28.8	--	--
lagged C3 C4 CASREP-days	0.316	0.0685	4.6	0.00002
lagged percent time in overhaul	3.48	0.918	3.8	0.0002

Once again, the model loses some of its ability to explain the variation in C3/C4 CASREP-days in the tradeoff to be able to forecast future values of readiness. Predictions for 24 of the 30 ships are within one standard error of the actual CASREP-days. The standard error itself, however, is 208 days, indicating the loss of precision due to the greater variability of the alternate measure of readiness as compared with the primary measure. Ten of the 30 predictions are within plus or minus 60 CASREP-days of the actual values, and 17 of the 30 are within plus or minus 90 CASREP-days of actual.

Due to the close relationship between the primary and alternate measures of readiness, the alternate model has the same difficulties as the primary model with the assumptions of no autocorrelation and homoscedasticity of residuals. Data transformation of the alternate model has the same effect and shortcomings as those discussed for the primary model.

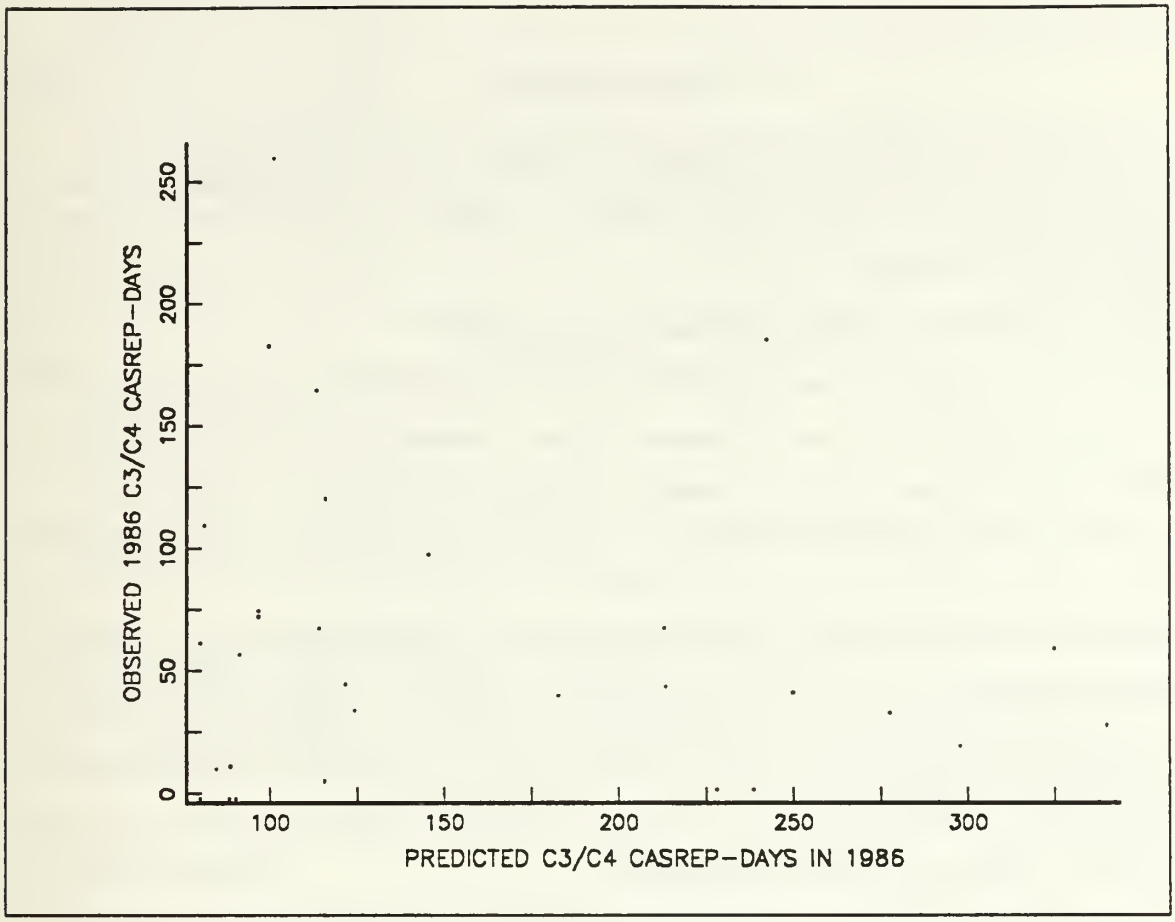

Figure 9. Results of Alternate Prediction Model: actual 1986 C3/C4 CASREP-days plotted against alternate model's predicted C3/C4 CASREP-days for 1986 using 1985 data

VI. CONCLUSIONS

It is important to note that the explanatory variables found to be significant in their relation to readiness do not cause ship readiness to behave as it does; rather they are merely related to readiness.

A. COMPARISON OF MEASURES OF READINESS

The alternate measure of readiness, C3 and C4 CASREP-days, is not significantly better in any apparent way than the primary OP-81 measure, time free of C3 and C4 CASREPs. The two are very closely related in this data set: since most ships have at most one C3 or C4 CASREP at a time, the two measures of readiness are simply alter egos.

This fact does not prevent the alternate measure of readiness from being useful in different circumstances--perhaps with a different set of ships at a different time, there could be enough simultaneous C3 and C4 CASREPs to create a significant difference in the two measures of readiness.

B. USEFUL EXPLANATORY VARIABLES

It is considerably easier to provide a fitted value for a past or current year's material readiness than to predict next year's material readiness for a ship. This fact is true for both measures of readiness. The most useful variables found by this study are repair parts ordered, previous year's readiness and previous year's time in overhaul. All three of these variables are easy to explain and collect data on.

Unfortunately, none of the VAMOSC variables can be used in predicting material readiness. It appears that the fiscal explanatory variables in the VAMOSC database are not sufficiently focused to be helpful. Due to this, the models developed are not useful for programming maintenance funding.

It would be helpful to discriminate between maintenance funds spent for repairing existing material problems and those funds spent for modernization and overhaul of older systems--this would enable associating each of these variables with the appropriate effect of CASREP termination (repair activities) or CASREP generation (overhaul/ modernization activity).

C. DATA COLLECTION

As discussed above, collecting separate data on funds spent to repair ships and funds spent to upgrade and overhaul them would be helpful.

Additionally, collecting more accurate data on personnel manning and turnover in the senior enlisted ranks (E4-E6 and E7-E9) among the Combat Systems and Engineering ratings could lead to good improvements in readiness models. Moreover, turnover and manning data can be projected into the future (similarly to time in overhaul), giving an ability to predict their future effect on maintenance, even when exact dates for personnel detaching and reporting are not known in advance.

D. GENERAL CONCLUSIONS

The models of ship readiness developed in this thesis do not succeed in their goal of assisting in the programming of Navy funds. Fiscal data available for the study are not sufficiently focused to be helpful in explaining ship readiness. The resulting models are capable of modest predictions of future ship readiness, but such predictions are not necessarily useful. It would be dangerous to avoid overhauls simply because they led to later C3 and C4 CASREPs: overhauls and modernization of our ships are required to keep them effective. The simplicity of the models developed here is helpful for some insight into ship material readiness and factors related to it, but the models are not helpful for planning budgets.

APPENDIX DESCRIPTION OF VARIABLES

The following is a listing of all of the explanatory variables involved in the study. Variables used in the model are denoted by an asterisk.

VAMOSC DATA

The hierarchical structure of the VAMOSC data set is reflected by the indentations below. The leftmost variables were aggregated by summing the variables beneath them and to the right. Units are dollars unless otherwise indicated.

Direct Unit Costs

- Total Personnel
  - Manpower
    - Organizational Maintenance Labor Manhours *
    - Officer Manpower
    - Enlisted Manpower
  - Temporary Additional Duty of Crew
- Material
  - Ship Petroleum, Oil, and Lubricants (POL)
    - Total Fuel
      - Fuel Underway
      - Fuel Not Underway
    - Other POL
    - Barrels of Fuel Consumed
      - Barrels Consumed Underway
      - Barrels Consumed Not Underway
  - Repair Parts
  - Supplies
    - Equipment and Equipage
    - Consumables
    - Ship Force Material *
  - Training Expendable Stores
    - Ammunition
    - Other Expendables
  - Repairables
    - Organizational Exchanges
    - Organizational Issues
  - Purchased Services

Direct Intermediate Maintenance Costs

- Afloat Maintenance Labor *
- Ashore Maintenance Labor *
- Material *
  - Afloat Repair Parts *
  - Ashore Repair Parts *
- Commercial Industrial Services

Direct Depot-Level Maintenance Costs

- Scheduled Ship Overhaul
  - Regular Overhaul (ROH)
    - Public Shipyard ROH
      - Overhead
      - Labor *
        - Labor Mandays *
      - Material *
    - Private Shipyard ROH *
    - Ship Repair Facility ROH
      - Overhead
      - Labor *
      - Material *
    - ROH Completion
  - Selected Restricted Availability (SRA)
    - Public Shipyard SRA
      - Overhead
      - Labor *
        - Labor Mandays *
      - Material *
    - Private Shipyard SRA *
    - Ship Repair Facility SRA
      - Overhead
      - Labor *
        - Labor Mandays *
      - Material *
- Unscheduled Ship Repair
  - Restricted Availabilities (RAV)
    - Public Shipyard RAV
      - Overhead
      - Labor *
        - Labor Mandays *
      - Material *
    - Private Shipyard RAV *
    - Ship Repair Facility RAV
      - Overhead
      - Labor *
      - Material *
  - Technical Availabilities (TAV)
    - Public Shipyard TAV
      - Overhead
      - Labor *
        - Labor Mandays *
      - Material *
    - Private Shipyard TAV *
    - Ship Repair Facility TAV
      - Overhead
      - Labor *
      - Material *

Fleet Modernization Program (FMP) *
- Public Shipyard FMP *
- Special Program Material *
- Other FMP
- Outfitting and Spares

Other Depot Costs
- Naval Aviation Depot *
  - Overhead
  - Labor *
  - Material *
- Field Change Installation *
- Rework *
  - Ordnance Rework *
  - Hull, Mechanical and Electrical Rework *
  - Electronics Rework *
- Design Services Allocation

CNA DATA

Manning levels are available relative to mobilization requirements and as raw counts of personnel.

Ship Activities

Percent of Time Deployed
Percent of Time Deployed to Forward Areas *
Percent of Time in Maintenance *
Percent of Time in Overhaul *
Percent of Time Gone from Homeport more than two months
Percent of Time Inport *
Percent of Time Underway
Hours Steaming Underway
Hours Steaming Not Underway *
Age of Ship *
Time Since Overhaul *
Time Since Deployment *
Time Since Departed on Deployment *
INSURV Inspection Held
- Percent of Preventive Maintenance Items Performed *
- INSURV Material Condition Index *

Change of Command Held
Fleet (Pacific or Atlantic Homeport) *
Training Inspections Held
Participation in Joint or Major Exercises

Commanding Officer Information

Relative Seniority of CO
CO Previous Experience as CO, Executive Officer, or Department Head
Time as CO of this Ship

Spare Parts Information

Total Repair Parts Ordered
Allowance (COSAL) and Non-Allowance Stocked Repair Parts Ordered *
Allowance and Non-Allowance Stocked Parts Ordered and Issued on Ship
Allowance Repair Parts Ordered
Allowance Repair Parts Ordered and Issued From Ship

Enlisted Manning Level and Turnover Data

Percent of New Personnel in Combat Systems Department, last three months
Percent of New Personnel in Engineering Department, last three months
Percent of New Personnel in Crew , last three months
Percent of New Personnel in Combat Systems Department, last six months *
Percent of New Personnel in Engineering Department, last six months *
Percent of New Personnel in Crew, last six months
Administrative Ratings Manning Level
Combat Systems Ratings Manning Level *
Engineering Ratings Manning Level *
Total Enlisted Manning Level
Manning Level of E4-E6 in Administrative Ratings
Manning Level of E4-E6 in Combat Systems Ratings *
Manning Level of E4-E6 in Engineering Ratings *
Manning Level of E1-E3 on Ship
Manning Level of E4-E6 on Ship
Manning Level of E7-E9 on Ship *

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